

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
28 February 2002 (28.02.2002)

PCT

(10) International Publication Number  
**WO 02/16979 A2**

(51) International Patent Classification<sup>7</sup>: **G02B 6/00**

(21) International Application Number: PCT/US01/26071

(22) International Filing Date: 21 August 2001 (21.08.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
09/645,723 24 August 2000 (24.08.2000) US

(71) Applicant: **SABEUS PHOTONICS, INC.** [US/US];  
3995 Via Oro Avenue, Long Beach, CA 90810 (US).

(72) Inventors: **STARODUBOV, Dmitry**; 233 S. Lorraine  
Boulevard, Los Angeles, CA 90004 (US). **TISHININ,**  
**Denis**; 575 Easton Avenue #18S, Somerset, NJ 08873  
(US).

(74) Agents: **DIENER, Michael, A.** et al.; Hale and Dorr LLP,  
60 State Street, Boston, MA 02109 (US).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

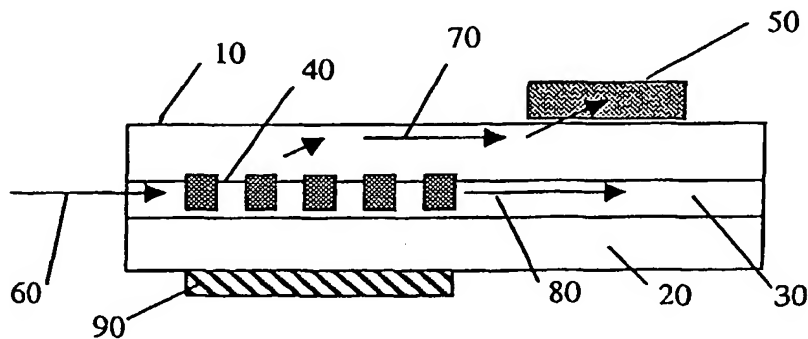
(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

**Published:**

— without international search report and to be republished upon receipt of that report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: FIBEROPTIC BUS, MODULATOR, DETECTOR AND EMITTER USING CLADDING MODE COUPLING



(57) Abstract: The present invention thus provides a simple, fiber-coupled, low-loss, and wavelength-selective semiconductor components that could be cascaded in series with minimal loss and connected in a simple manner.

WO 02/16979 A2

Best Available Copy

## **FIBEROPTIC BUS, MODULATOR, DETECTOR AND EMITTER USING CLADDING MODE COUPLING**

### **Field of Invention**

5        This invention relates to fiberoptic components, especially those for amplifying, modulating, emitting or detecting light in optical fibers.

### **Description of Related Art**

Optical fibers now form the backbone of the global telecommunications network. High-speed fiber optic communication systems use different wavelengths of  
10    light to transmit multiple channels of information simultaneously through a single-mode optical fiber. This technique is called wavelength division multiplexing (WDM). Although the Internet uses optical fibers to connect computers together, most computers still use electrical signals in semiconductor chips to process and distribute information. To provide communication between computers or even the links between  
15    the various components inside each computer with light signals of different wavelengths, a simple and inexpensive method should be found to transfer an electrical signal into a light signal of a particular wavelength in an optical fiber, and vice versa.

Receiving an individual optical channel requires a wavelength-selective  
20    detection method. One method to detect a single optical channel traveling in an optical fiber is to use an add/drop filter followed by an end-coupled semiconductor detector. To measure several channels, multiple add/drop filters can be cascaded. If there are many optical channels such as in a WDM system, a problem is caused by the loss that each add/drop filter introduces to the undropped channels. For example, if  
25    each add/drop filter has an insertion loss of 2 dB, then a 10-channel system with 10 add/drop filters in series will impose a decrease of power of 20 dB to the last channel (i.e., a loss of signal by a factor of 100). In a system with even more channels, some channels will suffer an even greater decrease of power.

An alternate approach for detecting a single channel in a multichannel system  
30    requires separating the channels using a wavelength multiplexer. In this design each channel detector typically has its own additional optical amplifier and band-pass filter to improve the signal-to-noise ratio. Single-mode fiber-coupled semiconductor

devices, however, are expensive and difficult to fabricate in large quantities. Aligning and packaging semiconductor chips with a small (~10 micron) fiber core is time-consuming and costly. These design and cost problems make it difficult to bring WDM fiber optic transmission to local networks.

5           In order to couple and extract light from a fiber's core mode, one can etch or polish through the fiber's cladding to the fiber's core (see e.g., U.S. Patent No. 5,502,785). This approach weakens the fiber, provides no wavelength selectivity, and is delicate and complicated.

10           One can use tilted Bragg gratings to couple light from a fiber core into free space at a certain location (see e.g., U.S. Patent No. 5,042,897). This design can work as a fiber spectrometer by using an array of detectors placed at a precise location outside the fiber. However, coupling to free space makes this design unstable, and detector arrays are expensive.

15           In Saeki, U.S. Patent No. 5,974,212, tilted Bragg gratings are used to reflect light to photodetectors at the side of the fiber at a location transverse to the gratings. Saeki does not use long period gratings or excite the cladding mode; rather, light is leaked to the cladding to the photodetector, which must be properly aligned with the grating. Such a tilted Bragg grating is not bi-directional, and its use can create alignment problems with a detector if the fiber has a twist in it, or if the photodetector  
20 is not properly aligned axially with the tilted Bragg grating.

          A detector array can be mounted in close vicinity to a chirped fiber grating for Fourier transform spectroscopy measurements (M. Froggatt, T. Erdogan, Opt. Lett. 24(14), 942, 1999). In this case precise alignment of an expensive detector array is still required.

25           In addition to the problem of detecting individual wavelength channels traveling in the core of an optical fiber, another problem is how to inject a single optical wavelength into the core of an optical fiber. A laser can be end-coupled to a core of an optical fiber, but this approach requires precise alignment between the small fiber core and the emitting region of the laser. Most semiconductor lasers emit  
30 light in an elliptical pattern that typically measures about 1 micron by 100 microns, so special optics are required to shape that light into the 10-micron diameter circular target presented by the fiber's core, and such optics are expensive and difficult to

align with the fiber. Additionally, the long-term stability of alignment of such optics is a serious problem.

Another problem is how to amplify light traveling in an optical fiber.

Semiconductor waveguide amplifiers have been used, but alignment of the input and output fibers with such waveguides is difficult and introduces additional optical loss. An alternate method is to use a section of erbium-doped fiber that is pumped by a laser, as in an erbium-doped fiber amplifier (EDFA). Such devices are presently very expensive.

Another problem is how to modulate light traveling in an optical fiber. A typical method is to modulate the laser light source, but such modulation can introduce unwanted frequency chirp onto the modulated light signal. An alternate method uses an external modulator formed, for example, from a lithium niobate crystal. However, this approach requires that the light be removed from the fiber, passed through the lithium niobate crystal, and then reinjected into another fiber, thereby introducing unwanted loss.

### Summary of the Invention

The present invention relates to the use of a simple, fiber-coupled, low-loss, and wavelength-selective component with a fiber and that can be provided with minimal loss and connected in a simple matter for detection, amplification, or other detection or processing of light in the fiber.

A chip, such as a semiconductor multiple quantum well structure or other structure that can convert light to an electrical signal, can be bonded to or next to the cladding of a fiber. A long period fiber grating is used to couple light from a core to excite a cladding mode of an optical fiber in a spectrally selective manner. Light in the cladding can then be detected, amplified, or modulated by the chip mounted to or at the side of the fiber and axially spaced from the grating. Additional long period gratings in the fiber can be used to divert light from the fiber cladding back into the fiber core, and Bragg gratings can additionally be used to reflect light.

The fiber preferably has a polygonal cross-section with at least some flat sides on the cladding for mounting a chip or other element against the fibers.

This structure thus meets a need for a simple and reliable method of connecting semiconductor chips and optical fibers in a wavelength-selective manner, including in computers themselves in addition to backbone communications. One or

more chips can be used for a number of purposes, including detection of light, power normalization, detection of changes from a desired wavelength, and wavelength determination. By using a long period grating to excite a cladding mode, the chip need not be aligned axially or circumferentially with the grating, but can be axially spaced from the grating and offset circumferentially. Other features and advantages will become apparent from the following detailed description, drawings, and claims.

### Brief Description of the Drawings

Fig. 1 is a cross-section of a wavelength-selective detector with a long-period fiber grating and a semiconductor chip mounted directly onto the side of the fiber.

Fig. 2 shows a typical response of the selective detector of Fig. 1.

Fig. 3 is a cross-section of an optical transmitter mounted on the side of the fiber with a long period grating to couple light from the cladding into the fiber core.

Fig. 4 is a cross-section of a fiber-coupled semiconductor emitter that uses end-coupling into the cladding of the fiber and then grating-assisted coupling from the cladding into the fiber core.

Fig. 5 is a side view of a chip according to the present invention.

Fig. 6 is a cross-sectional view of a semiconductor structure having a distributed feedback (DFB) mirror and multiple quantum well structure, which is bonded to the fiber surface for efficient coupling with light in the fiber cladding.

Fig. 7 shows a fiber with polygonal cross section. The flat sides can be used to more easily attach elements and can be used as a laser cavity for lasing across the fiber.

Fig. 8 is a cross-section of a fiber attached to a planar waveguide circuit.

Fig. 9 is a cross-section of a device in which an amplifier is mounted to a side of a fiber between two long period gratings.

Fig. 10 is a schematic block diagram of a feedback system according to the present invention for controlling power and/or wavelength.

### Detailed Description

Fig. 1 illustrates an embodiment of the present invention. An optical fiber 10 has a light-transmitting cladding 20 and a core 30. The fiber can be a glass optical fiber, or it can be made of a different suitable material, such as a polymer. A long-period grating 40, i.e., a grating with a period of about 10-1000 microns, is formed in

core 30, as shown, or in cladding 20, or both in core 30 and cladding 20 for resonantly coupling some of light 60 from core 30 into cladding 20 at a desired wavelength that is determined by the spacing of elements in grating 40. Light not coupled by grating 40 continues as light 80 in core 30. Fiber 10 thus supports propagation of light in a cladding mode, which can be accomplished, for example, by removing from the fiber a protective polymer coating so that there is a glass/air boundary outside of cladding 20.

According to the present invention, a chip 50 is mounted on a side of fiber 10 to make optical and mechanical contact with cladding 20. This chip 50 can be a semiconductor chip or some other planar optical structure, such as a polymer light guide or a glass light guide.

Chip 50 can be directly bonded to a surface of cladding 20 or glued using transparent glue, such as an epoxy, at a location that is axially spaced from long period grating 40. The circumferential position of chip 50 is not critical. A thin dielectric layer can be interposed between chip 50 and cladding 20 to enhance optical transmission between them. Chip 50 is positioned such that a portion of light 70 traveling in cladding 20 is at least partially absorbed in chip 50.

Chip 50 can provide an electrical signal, thereby producing a desired wavelength-selective detection of light 60 originally propagating in core 30 of fiber 10. A tuning element 90 can also be used to alter the resonant wavelength of grating 40 to enable light with a particularly desired wavelength to be detected. The tuning element could, for example, include a mechanical system to physically stretch fiber 10 or to heat fiber 10 to alter the resonance of grating 40. By constructing different grating patterns inside the fiber, the spectrum of the long-period grating could be designed to have arbitrary spectral shape. For example, the grating could have multiple resonances for detecting multiple wavelengths, or the grating could have a saw-tooth spectral shape to enable precise wavelength measurement.

The spectrum of grating 40 can be designed to pass light at a center frequency and to deflect light from the core to the cladding at either side of the central wavelength. (See Starodubov et al. OFC, 19-98, post-deadline paper PD8). Such a grating can thus be used to monitor any deviation of wavelength from the central wavelength of light in the fiber core. Any drifting of the light wavelength from the central wavelength increases the coupling from fiber core to fiber cladding, and

thereby increases the signal detected by chip 50. A simple feedback circuit between the chip and the light source can therefore be used to keep the light wavelength fixed at the central wavelength.

5 Fiber gratings used in the present invention can be polarization-selective (see for example A. S. Kurkov et al, Electron. Lett. 33 (7) 616, 1997). If the fiber core, fiber cladding, or the fiber grating have deviations from a cylindrical symmetric geometry, then one polarization of light from the fiber core will preferentially be sent to the cladding mode from the core and back in a given wavelength range.

Referring to Fig. 10, a light source 460 is wavelength-stabilized using the  
10 detector of the present invention. Light source 460 emits light into optical fiber 10. A detector 480 as described in conjunction with Fig. 1 is wavelength-selective and attached to fiber 10. Detector 480 detects a spectral deviation of light source 460 from a desired spectrum and sends a signal back to light source 460 through a  
15 feedback connection 470. Control elements inside the light source 460 change the output of the light source until the signal from the detector 480 matches the output from the desired spectrum.

For wavelength monitoring it is necessary to be able to differentiate between a change in wavelength and a change in power. This difference can be detected in the present invention by using the almost spectrally insensitive coupling between core  
20 and cladding that occurs when a fiber is bent. A signal from an additional detector placed in the vicinity of such a fiber microbend can be used with the spectrally sensitive detector described in Fig. 1 above to normalize power changes in the light signal, and thereby distinguish changes in wavelength from changes in power. This additional detection element can be placed either before or after a wavelength-  
25 selective element. Alternatively a signal could be extracted directly from the core of the fiber (in a pigtailed or terminated fiber), either before or after the detector unit, and could be used for power normalization.

This wavelength selective light detection method can be used in a variety of devices and systems including fiberoptic sensors, decoders, and wavelength meters.  
30 Such semiconductor elements with direct side coupling to a fiber can be used in a WDM fiberoptic computer bus, and this bus will be 10-1000 times faster than typical 500MHz computer buses currently used. Such a fiberoptic bus will also be splice-compatible with existing fiberoptic links. A space can be provided on a computer's

processor or controller chip where a fiber bus is attached sideways using a drop of ordinary optical glue. Such compatibility between computer buses and fiberoptic links could substantially improve next generations of the Internet.

Fig. 9 shows a system in which chip 50 is an amplifier for amplifying light 71 in the chip from light 70 in the cladding. This device uses two long period gratings 41, 42 for transforming light from core to cladding and cladding to core, respectively. Chip 50 is axially between gratings 41 and 42 to allow light to pass from grating 41 to chip 50 to grating 42. Chip 50 can be a semiconductor optical amplifier. Alternative, chip 50 can be a hybrid waveguide amplifier such as Er-doped waveguide amplifier (EWDA) which is pumped by a semiconductor laser pump.

Fig. 2 shows an example of a spectral response of a detector in a system such as that shown in Fig. 1. The detector used to create the response had an apodized long-period grating in a commercially available photosensitive optical fiber, and a multiple quantum well semiconductor detector chip measuring 100 microns by 100 microns. The chip was glued on a sub-mount measuring 3 mm x 1 mm to provide suitable electrical contacts. The resulting spectrally selective detector had a full-width-at-half-maximum (FWHM) of ~1.5 nm (~200 GHz).

Fig. 3 shows how the system of Fig. 1 can also be used to couple light into fiber 10 from a light-emitting semiconductor chip 50 mounted on a side of fiber 10. Chip 50 emits light 71 into fiber cladding 20, where the light is further deflected into fiber core 30 by long-period grating 40. A Bragg grating 102, i.e., a short period grating with a typical period of about 0.1-2 microns, reflects some light 101 back towards chip 50. It is known that such optical feedback into a lasing chip can improve the efficiency of optical coupling of the launched light into a fiber core. Light 61 continues in the fiber core after Bragg grating 102. As with Fig. 1, a tuning element 90 is also provided to control the resonant wavelength of grating 40. By providing electrical or optical power to the chip, this embodiment can function as an optical amplifier. The amplifier design could omit Bragg grating 102. Alternatively the amplifier design may have two Bragg gratings to induce lasing at a wavelength removed from the designed spectral range of the amplifier. Such lasing operation will clamp the gain of the amplifier.

Fig. 4 shows an example of a device that uses two semiconductor chips, a long-period grating 140, and a Bragg grating 145. Fiber 10 has a cladding 120 and a



core 130. Long-period fiber grating 140 couples light from core 130 into cladding 120 to produce light 175 in the cladding mode. Bragg grating 145 in fiber core 130 reflects back light 180 traveling in the core 30 to produce reflected light 190. Bragg grating 145 is located downstream of long-period grating 140. Optical detecting chips 150 and 160 are mounted on the side of fiber 10 on either side of long-period grating 140.

These detecting chips 150 and 160 could be made from semiconductor or polymer materials or both. A waveguide structure may be a polymer waveguide structure made, for example, of polyimide or PMMA (poly methyl methacrylate ).

10 The waveguide structure may be a glass waveguide structure, such as a silica glass waveguide. The waveguide structure can be deposited on top of a semiconductor substrate or integrated circuit. Alternatively the waveguide structure can be made of an optical crystal, for example, lithium niobate.

Incident light 170 to core 130 is partially transferred into light 175 in cladding 120 by long-period grating 140. Light 175 reaches semiconductor chip 150 and is at least partially absorbed in chip 150. Light 180, which passes grating 140, is back-reflected by a Bragg grating 145 to form light 190. The Bragg grating reflection is spectrally selective. Usually Bragg gratings have narrower spectral features than long-period gratings. The desired reflection spectrum of the Bragg grating could be

20 obtained by varying the grating parameters, such as length, period, and the refractive-index depth and pattern. Reflected light 190 is partially transferred into cladding 120 by long-period grating 140 and then absorbed by chip 160. By analyzing electrical signals from chips 150 and 160, it is possible to introduce more complicated functionality to this detection module.

25 For example, a two-grating device could be used for high-accuracy determination of the wavelength of a narrow-band light signal. The long-period grating, with its wide resonance, will determine the approximate wavelength of a light signal into detector 150. A Bragg grating, possibly having multiple resonances, will give a more precise wavelength measurement using detector 160. The long-period

30 grating will reveal which of the narrow Bragg resonances is matched to the light signal.

Fig. 5 shows an example of a semiconductor structure 220 placed on the side of the fiber 10. This attached semiconductor structure 220 can be used for

amplification or modulation of a light signal propagating in a fiber. Semiconductor structure 220 is placed in close contact with a fiber surface 210. This structure can be a multiple quantum well structure. A top layer 230 may be added to the structure to reflect light. Layer 230 could, for example, be a distributed-feedback (DFB) mirror  
5 made of semiconductor layers having different refractive indices. The semiconductor chip is bonded to fiber surface 210. The bonding process includes heating the chip and the fiber together in contact. Diffusion at high temperature provides connection of the semiconductor and the fiber.

In experiments, bonding was performed in an atmosphere of hydrogen. For  
10 InP- based chips, an optimal bonding temperature was determined to be around 400°C. For GaAs based chips, an optimal bonding temperature was determined to be around 700°C. Optical glues could be used to ensure stable contact between the fiber and the chip.

A thin quantum well device with a DFB structure can modulate light  
15 transmission in the fiber. This same semiconductor structure can be used to launch light into the fiber cladding or even amplify the light traveling in the cladding mode.

To construct a fiber light source, a semiconductor structure with a mirror on its back face can be attached to one side of the fiber to create optical gain for selected wavelengths of light. A similar semiconductor structure or a mirror can be positioned  
20 on an opposite side of the fiber at the same location as the first semiconductor structure. These two structures can form a laser cavity with light oscillating between them. This light can be deflected by a Bragg grating in the fiber core to direct the oscillating light along the fiber core.

Using a similar geometry, an optical amplifier with clamped gain for a  
25 cladding mode of the fiber can be constructed as follows. A semiconductor structure with a mirror on its back face is attached to one side of the fiber to create optical gain for selected wavelengths of light. A similar semiconductor structure or a mirror can be positioned on an opposite side of the fiber at the same location as the first semiconductor structure. These two structures can form a laser cavity with light  
30 oscillating between them. This light clamps the gain of the semiconductor amplifier(s). Another light beam travelling in a cladding mode of the fiber can experience gain from this structure.

Fig. 6 shows a device similar in design to those previously described and which is used to efficiently couple light from a semiconductor laser into a core 30 of an optical fiber 10. This geometry is useful for coupling light from large area, high-power laser emitters or light-emitting diodes into a fiber having a small core.

5 Collimating optics 270 project light from light-emitter 240 onto the fiber surface and excites a cladding mode of fiber 10. Cladding 20 is coupled into core 30 of fiber 10 by a long-period fiber grating 40. Light 300 propagates in the core of the fiber. A Bragg grating reflector 310 in core 30 provides optical feedback to light source 240. A front facet 280 and an emitter output facet 260 can be coated with antireflection coating  
10 and/or have a Brewster angle selected to avoid back reflections into the light emitter. A back facet 250 of emitter is a high-reflection mirror. The resulting output signal 320 travels in the core of the fiber. An advantage of this device is that the light from the emitter is coupled into the large area of the fiber cladding and not just the fiber core. For a typical single-mode fiber, with core diameter 10 micron and cladding diameter  
15 125 micron, this increases target size by more than a factor of ~150.

The cross section of the fiber can be circular, or it can have a shape other than circular. Fig. 7 shows how an optical fiber with one or more flat and planar surfaces 340 provides better mechanical contact between a chip 50 mounted on the outside of the fiber. These flat surfaces can be particularly useful for coupling of light from the  
20 fiber sideways. The cross section of the fiber may be a polygon with the number of sides greater than 3. For example a polygon with about 20 sides can be spliced to a standard cylindrical fiber without much loss. Sharp edges 350 of the fiber could be made curved either by mechanically polishing or fire polishing of the fiber perform to increase the strength of the resulting fiber.

25 Chip 50 can be an amplifier, an electroabsorption modulator, or a DFB mirror. There can be more than one semiconductor element 50 mounted on the sides of the optical fiber, and these elements can be used for amplification of light signals having different wavelengths. The combination of fiber and one or more chips 50 mounted on the side of the fiber can operate as a light source with light emission 360 propagating  
30 across the fiber.

Fig. 8 shows a cross section of the fiber attached to a substrate having a flat surface. Fiber 370 with preferably polygonal cross section can be attached to flat substrates. A substrate 390 can be a semiconductor or an optical material that is not a

semiconductor. The substrate, for example, can be a glass substrate, an optical crystal substrate, such as lithium niobate, or a composite substrate made of a combination of several materials.

5 Several fibers can be attached to a single substrate. For example a single substrate with multiple integrated elements can be attached to multiple fibers. The elements on the substrate can be used to amplify, modulate and switch the signals coming from and returning to the multiple optical fibers.

Optical fibers may be tapered for use in the present invention. Such tapering can be used to decrease the size of the substrate required for mounting and also to  
10 modify the optical coupling.

Substrate 390 may have optical waveguide elements 400. The substrate can also have grating elements (not shown) to improve the desired coupling.

Optical coupling could be achieved between an optical fiber and a planar waveguide in the substrate. Fiber 370 with polygonal cross-section can be mounted in  
15 the region of the substrate in proximity to a planar waveguide 400. The fiber can contain a grating to enhance the coupling between the core 380 of optical fiber and the waveguide element 400 of the substrate. This grating can be a long-period fiber grating formed in the core of the optical fiber. The optical waveguide 400 can be a light guiding region of a semiconductor laser. The waveguide 400 can also have a  
20 periodic element (not shown) to improve the desired coupling to optical fiber.

The substrate can have the combination of optical and electronic elements in it. For example a semiconductor substrate with a processor thereon can also have a transceiver module and an optical fiber attached to it in order to have a direct access to optical network.

25 Although the description above contains many specificities, these should not be construed as limiting the scope of the invention by merely providing illustrations of some of the presently preferred embodiments of this invention. Thus the scope of the invention should be determined by the appended claims and their legal equivalents, rather than by the examples given.

30 What is claimed is:

Claims

1. An optical device comprising:  
  
an optical fiber having a core and a cladding that supports cladding mode propagation;  
  
5 a long period grating for coupling light between the core and the cladding; and  
  
a semiconductor element attached at a side of the fiber at a location axially spaced along the fiber from the long period grating such that the element has optical coupling with the cladding mode.
- 10 2. The device of claim 1, where the cladding has a flat surface for mounting the semiconductor element.
3. The device of claim 1, wherein the fiber has a polygonal cross section.
4. The device of claim 3, wherein the number of flat sides of the fiber is at least 4.
- 15 5. The device of claim 1, wherein the semiconductor element is bonded directly to the fiber surface to change the power of light in the cladding mode.
6. The device of claim 1, wherein the semiconductor element measures a cladding mode signal.
7. The device of claim 6, further comprising a light source, and a  
20 feedback loop between the semiconductor element and the light source.
8. The device of claim 7, wherein the feedback loop causes the light source to produce light with a desired wavelength spectrum based on a wavelength determined by a period of the grating.

9. The device of claim 1, wherein the semiconductor element includes a quantum well device.

10. The device of claim 1, wherein the semiconductor element includes an amplifier for receiving and amplifying light from the cladding and for providing  
5 amplified light into the cladding.

11. The device of claim 1, further comprising a light source and collimating optics for providing light into both the core and the cladding of the fibers at the same time.

12. The device of claim 11, further comprising a long period grating in the  
10 fiber for coupling light from the cladding into the core.

13. The device of claim 1, further comprising a tuner for altering the detected wavelength of the long period grating.

14. The device of claim 1, wherein the semiconductor element provides a signal indicating the wavelength of detected light.

15. The device of claim 1, further comprising a Bragg grating as a reflector  
15 in the core to lock the wavelength of the emitter.

16. The device of claim 1, further comprising a second long period grating, wherein the element is positioned axially between the long period gratings and allows light to pass from one grating to the element to the other grating.

20 17. The device of claim 1 where the grating coupling is polarization-dependent.

18. The device of claim 1, wherein the element is a portion of an Er-doped waveguide amplifier (EWDA) or a Er-doped fiber amplifier (EDFA).

19. A device comprising an optical fiber having a core and a cladding with a finite number of sides greater than 3 to include flat sides in the cladding, and a semiconductor element mounted at one of the flat sides of the cladding of the fiber.

20. The device of claim 19, wherein the element includes a quantum well device.

21. The device of claim 19, wherein the element includes a device for converting received light into an electrical signal representative of the light.

22. An optical system comprising:  
a light source;  
an optical fiber having a core and a cladding;  
a grating for providing light from the core into the cladding for propagation in a cladding mode;

a chip mounted to the cladding for converting detected light to an electrical signal; and  
a feedback loop coupling the chip and the light source for maintaining the light at a desired wavelength based on a period of the grating.

23. The system of claim 22, wherein the light source includes a laser, the system further comprising collimating optics for projecting light from the source to the core of the fiber.

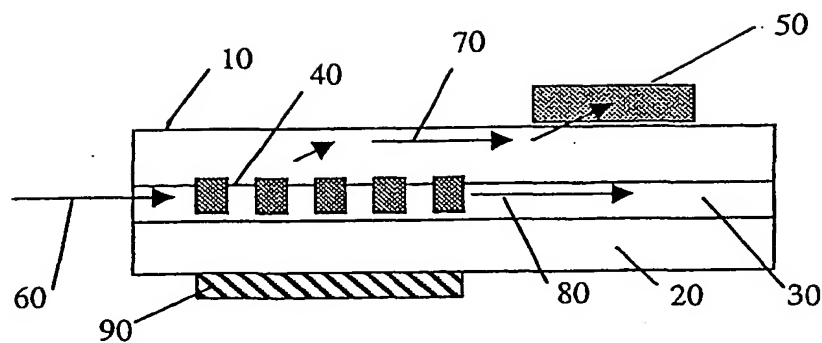


Figure 1

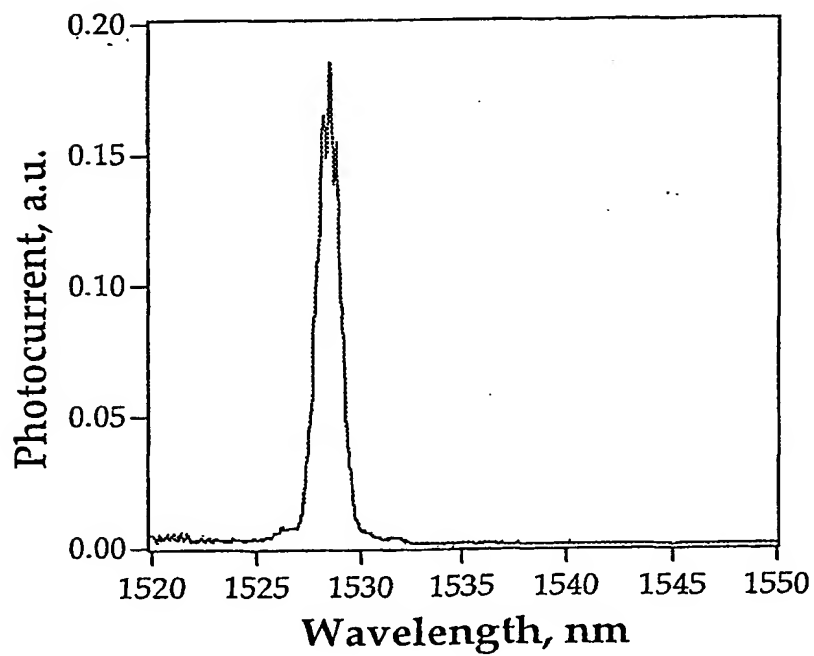


Figure 2



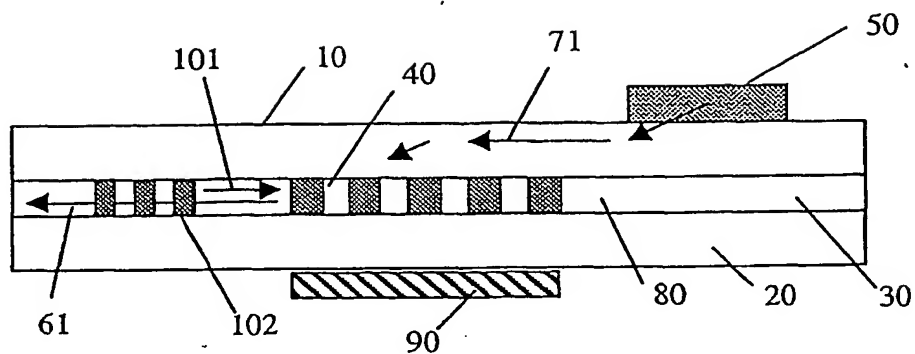


Figure 3

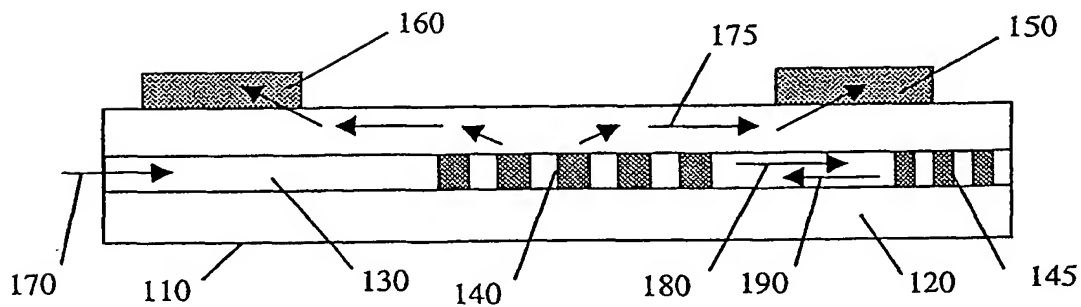


Figure 4

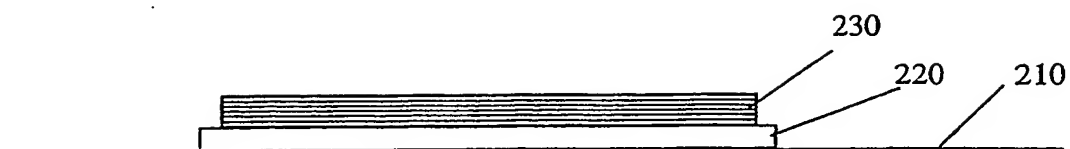


Figure 5

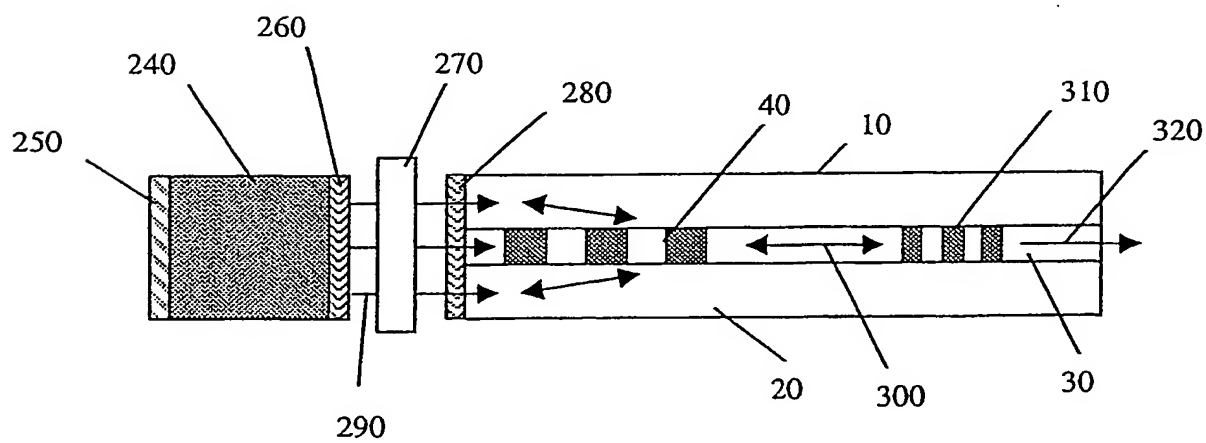


Figure 6

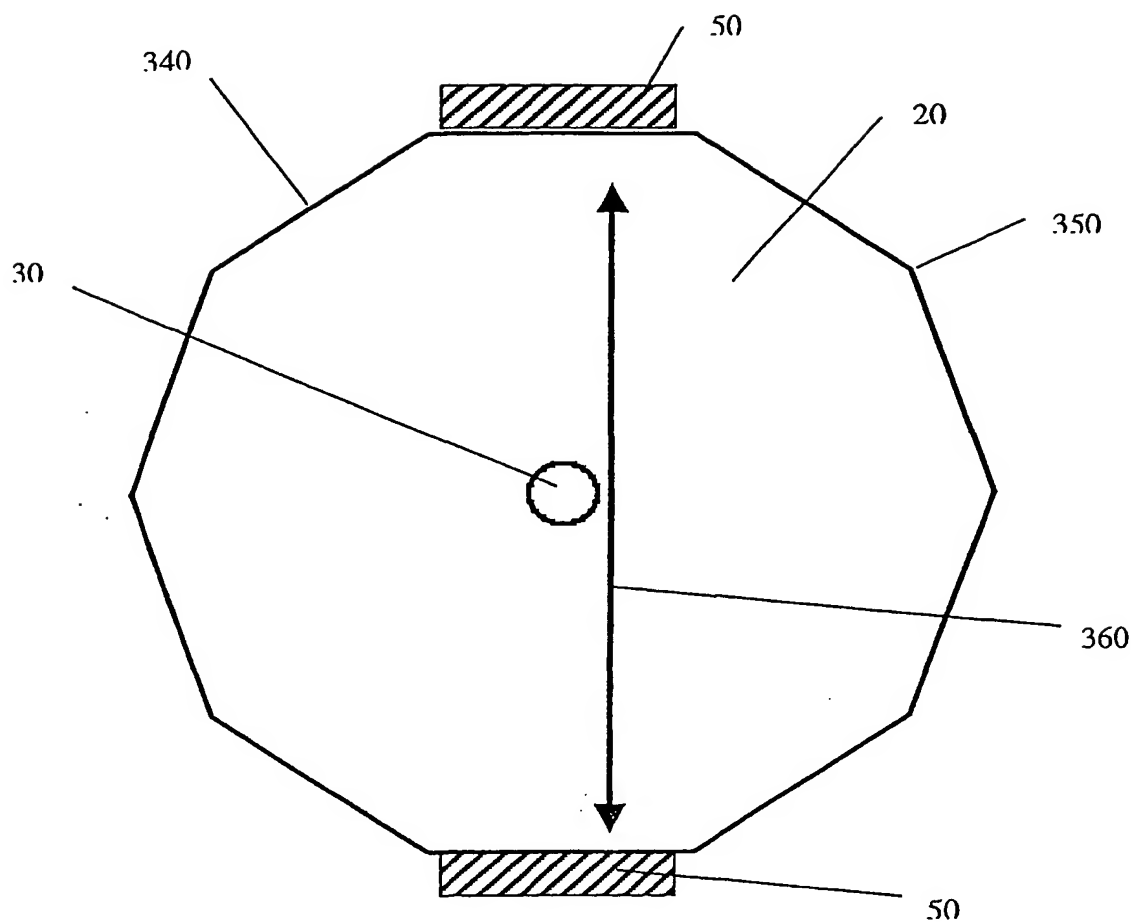


Figure 7

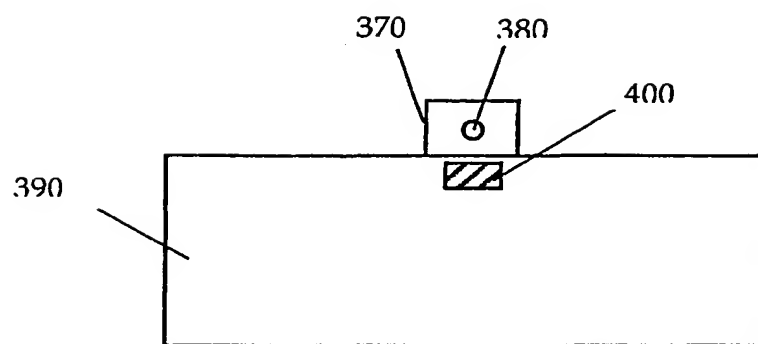


Figure 8

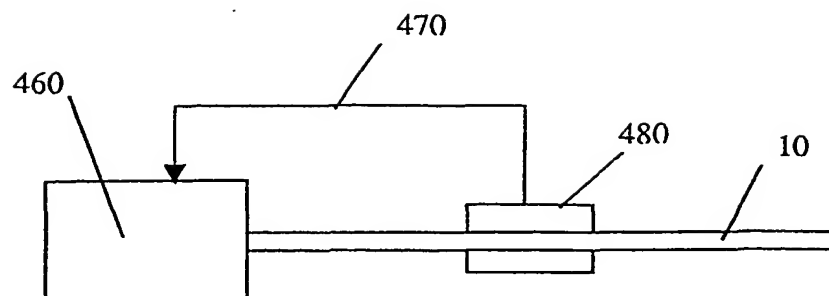


Figure 10

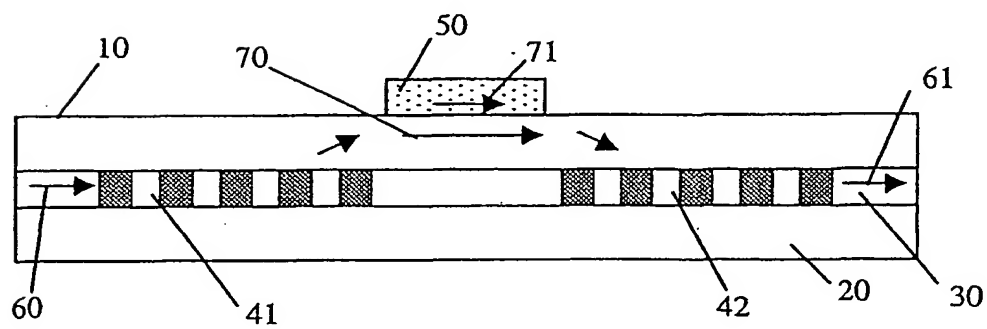


Figure 9

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization  
International Bureau



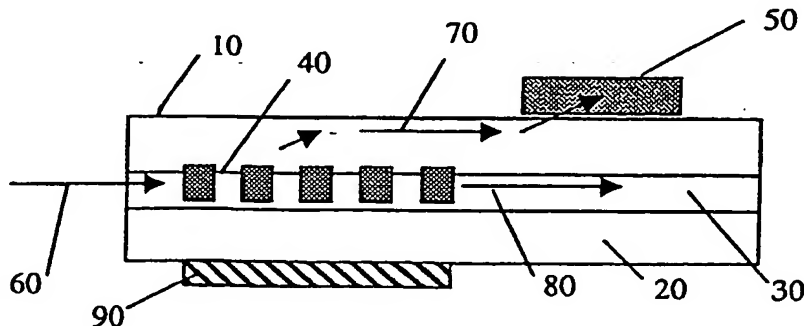
(43) International Publication Date  
28 February 2002 (28.02.2002)

PCT

(10) International Publication Number  
WO 02/016979 A3

- (51) International Patent Classification<sup>7</sup>: G02B 6/16, 6/14
- (21) International Application Number: PCT/US01/26071
- (22) International Filing Date: 21 August 2001 (21.08.2001)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:  
09/645,723 24 August 2000 (24.08.2000) US
- (71) Applicant: SABEUS PHOTONICS, INC. [US/US];  
20630 Nordhoff Street, Chatsworth, CA 91311 (US).
- (72) Inventors: STARODUBOV, Dmitry; 233 S. Lorraine  
Boulevard, Los Angeles, CA 90004 (US). TISHININ,  
Denis; 575 Easton Avenue #18S, Somerset, NJ 08873  
(US).
- (74) Agent: FITZGERALD, John K.; Fulwider Patton Lee &  
Utecht, LLP, Howard Hughes Center, 6060 Center Drive,  
Tenth Floor, Los Angeles, CA 90045 (US).
- (81) Designated States (*national*): AE, AG, AL, AM, AT, AU,  
AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU,  
CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM,  
HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK,  
LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX,  
MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL,  
TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.
- (84) Designated States (*regional*): ARIPO patent (GH, GM,  
KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian  
patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European  
patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE,  
IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF,  
CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD,  
TG).
- Published:  
— with international search report
- (88) Date of publication of the international search report:  
17 April 2003
- For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: FIBEROPTIC BUS, MODULATOR, DETECTOR AND EMITTER USING CLADDING MODE COUPLING



(57) Abstract: The present invention thus provides a simple, fiber-coupled, low-loss, and wavelength-selective semiconductor components that could be cascaded in series with minimal loss and connected in a simple manner. It comprises an optical fiber having a core (30) and a cladding (20) that supports cladding mode propagation, a long period grating (40) for coupling light between the core and the cladding and a semiconductor element (50) attached at a side of the fiber such that the element has optical coupling with the cladding mode.

WO 02/016979 A3

## INTERNATIONAL SEARCH REPORT

International Application No  
PCT/US 01/26071

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G02B6/16 G02B6/14

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G02B G01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 058 226 A (STARODUBOV DMITRY) 2 May 2000 (2000-05-02) column 5, line 1-9 column 7, line 59 -column 8, line 32 figures 5,8	1, 5, 15, 16
Y	---	2, 6, 14
Y	US 5 647 039 A (JUDKINS JUSTIN BOYD ET AL) 8 July 1997 (1997-07-08) column 5, line 11, 12 column 6, line 65 -column 7, line 4 figure 1	2, 6, 14
A	EP 0 989 424 A (LUCENT TECHNOLOGIES INC) 29 March 2000 (2000-03-29) paragraphs '0025!', '0026! ---	7
	-/-	

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

## \* Special categories of cited documents:

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
- \*E\* earlier document but published on or after the international filing date
- \*L\* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- \*O\* document referring to an oral disclosure, use, exhibition or other means
- \*P\* document published prior to the international filing date but later than the priority date claimed

- \*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- \*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- \*Y\* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- \*Z\* document member of the same patent family

Date of the actual completion of the international search

5 December 2002

Date of mailing of the international search report

17.12.02

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

Authorized officer

Verdrager, V

# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/US 01/26071

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KURKOV A S ET AL: "Long-period fibre grating as a wavelength selective polarisation element" ELECTRONICS LETTERS, IEE STEVENAGE, GB, vol. 33, no. 7, 27 March 1997 (1997-03-27), pages 616-617, XP006007289 ISSN: 0013-5194 cited in the application page 617, column 2, paragraph 1	17
A	US 6 021 240 A (MURPHY KENT A ET AL) 1 February 2000 (2000-02-01) column 4, line 20-49 figure 4	1,16
A	DE 198 43 164 A (HARTING ELEKTRO OPTISCHE BAUTE) 20 April 2000 (2000-04-20) column 10, line 53 -column 11, line 3 figure 21	19
A	WO 99 40482 A (UNIV NEW MEXICO) 12 August 1999 (1999-08-12) page 23, line 9-28 figure 3	19
A	US 6 002 822 A (STRASSER THOMAS A ET AL) 14 December 1999 (1999-12-14) column 3, line 27 -column 4, line 24 column 8, line 6-19 figure 2	22,23
A	US 5 999 671 A (LEMAIRE PAUL JOSEPH ET AL) 7 December 1999 (1999-12-07) column 4, line 43-60	22,23



# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US 01/26071

## Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:  
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☒ No protest accompanied the payment of additional search fees.

**FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210**

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-18

Claim 1 refers to an optical fiber having a core and a cladding with a long period grating and a semiconductor element attached at a side of the fiber at a location axially spaced from the long period grating.

2. Claims: 19-21

Claim 19 refers to an optical fiber with a finite number of sides greater than 3 and a semiconductor element mounted at one of the flat sides of the cladding.

3. Claims: 22-23

Claim 22 refers to an optical system comprising a light source, an optical fiber, a grating, a chip and a feedback loop coupling the chip and the light source.

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 01/26071

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 6058226	A	02-05-2000	NONE	
US 5647039	A	08-07-1997	NONE	
EP 0989424	A	29-03-2000	US 6111999 A EP 0989424 A2 JP 2000098316 A	29-08-2000 29-03-2000 07-04-2000
US 6021240	A	01-02-2000	US 6343168 B1	29-01-2002
DE 19843164	A	20-04-2000	DE 19843164 A1	20-04-2000
WO 9940482	A	12-08-1999	CA 2320107 A1 EP 1062543 A1 WO 9940482 A1 US 6221565 B1 US 2002119400 A1	12-08-1999 27-12-2000 12-08-1999 24-04-2001 29-08-2002
US 6002822	A	14-12-1999	US 5832156 A DE 69714378 D1 DE 69714378 T2 EP 0840150 A2 JP 10133054 A US 5850302 A	03-11-1998 05-09-2002 14-11-2002 06-05-1998 22-05-1998 15-12-1998
US 5999671	A	07-12-1999	NONE	

**This Page is Inserted by IFW Indexing and Scanning  
Operations and is not part of the Official Record**

**BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

☒ **BLACK BORDERS**

☒ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**

☒ **FADED TEXT OR DRAWING**

☐ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**

☐ **SKEWED/SLANTED IMAGES**

☒ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**

☐ **GRAY SCALE DOCUMENTS**

☐ **LINES OR MARKS ON ORIGINAL DOCUMENT**

☐ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**

☐ **OTHER:** \_\_\_\_\_

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.**